

# The Ly $\alpha$ Flux Power Spectrum

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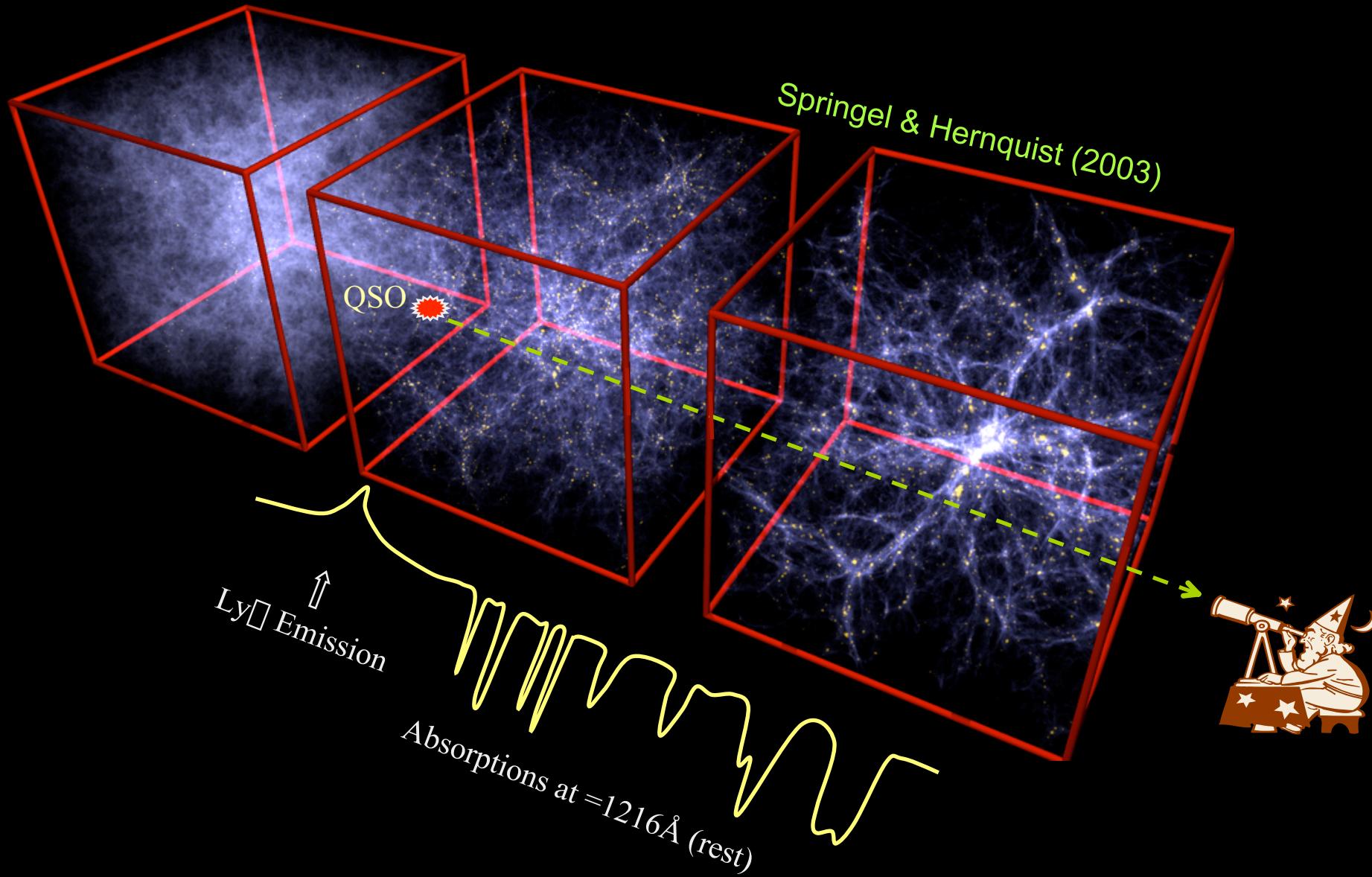
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# Outline

- ④ Simulating the Ly $\alpha$  forest
- ④ Pseudo-hydro techniques (PS)
- ④ Flux power spectrum (PS)
- ④ Systematics
- ④ Cosmological applications
- ④ Summary
- ④ Systematics
- ④ Summary
- ④ pseudo-hydro vs. full-hydro, matter vs. flux, non-Gaussianity ...
- ④ Summary

# The Ly $\alpha$ Forest



# Pseudo-hydro Techniques

- ® Equation of state (Hui & Gnedin 1997)

$$T = T_0 (\rho_b / \bar{\rho}_b)^{\gamma-1} \quad 1.3 \leq \gamma \leq 1.6 \quad T_0 \approx 10^4 \text{ K}$$

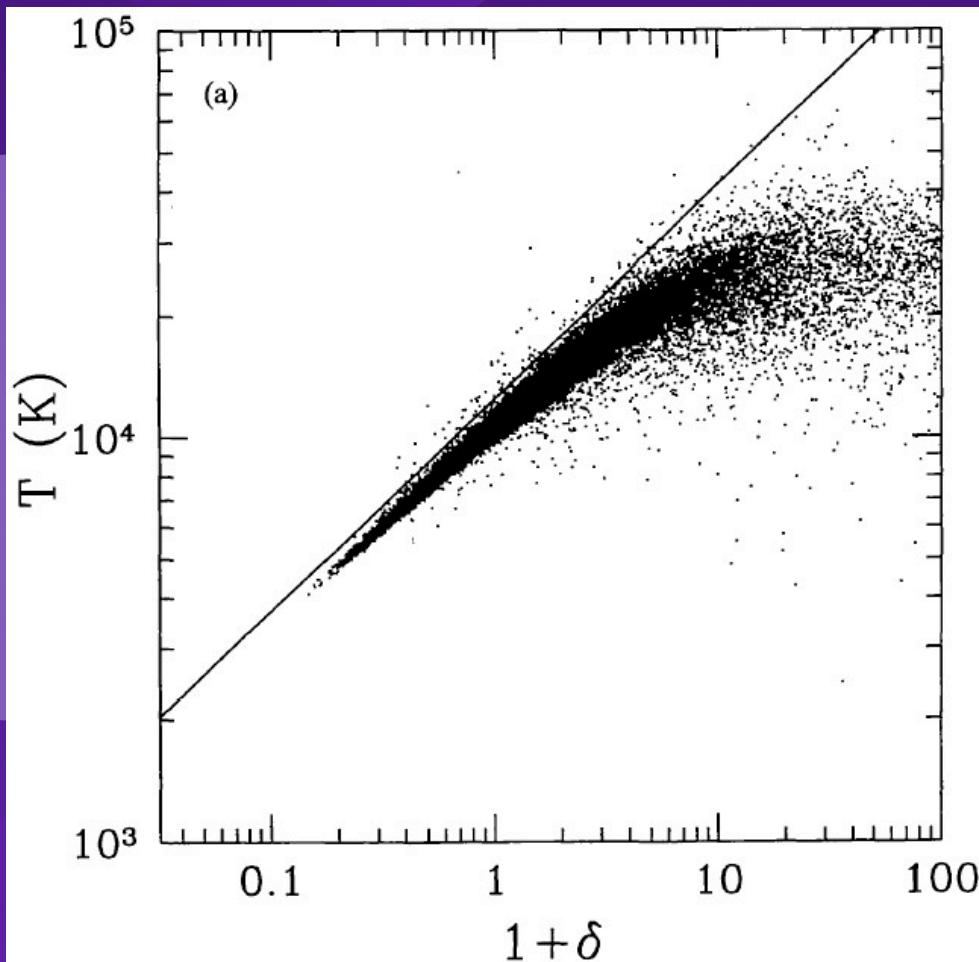
- ® Optical depth (Croft et al. 1998)

$$\tau = A (\rho_b / \bar{\rho}_b)^\beta \quad \beta = 2.7 - 0.7\gamma \quad F = e^{-\tau}$$

- ®  $\rho_b / \bar{\rho}_b \propto \rho_{dm} / \bar{\rho}_{dm}$

- ® Or, replacing the EOS by thermal equilibrium and ionization equilibrium

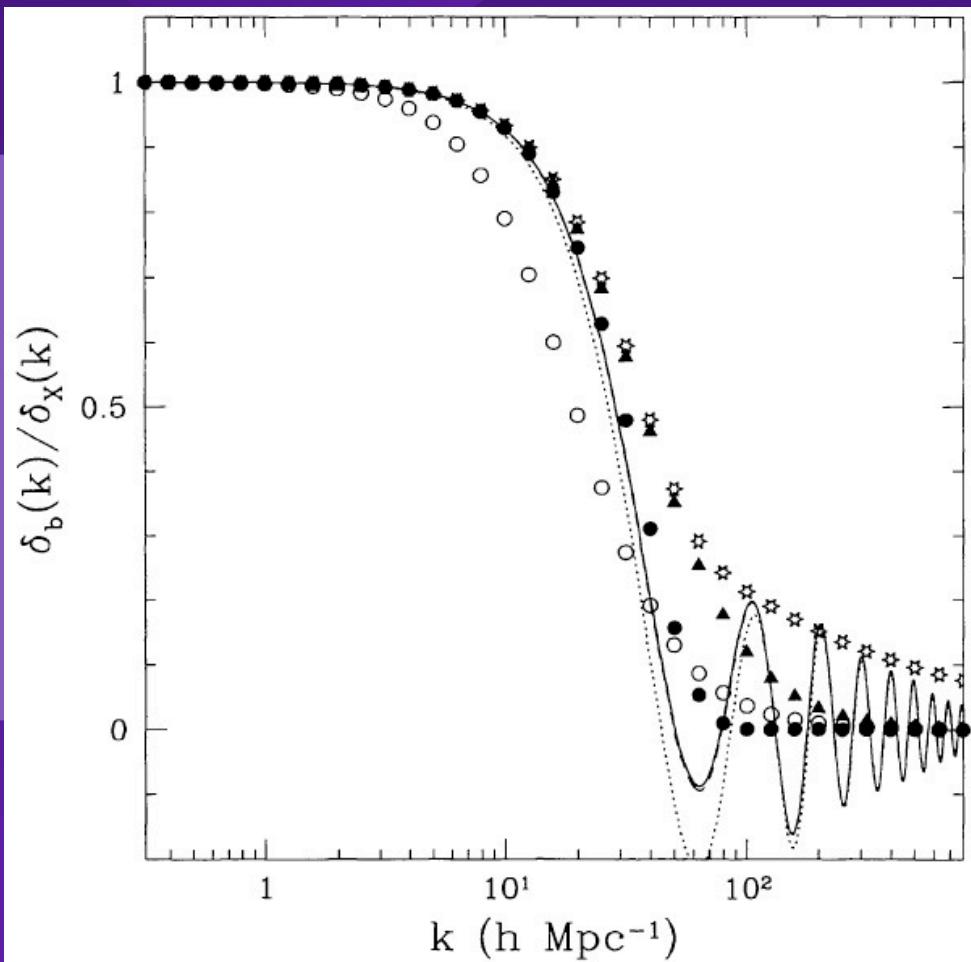
# Equation of State of the IGM



LCDM hydro  
simulation,  $z = 4$

Hui & Gnedin (1997)

# Baryons vs. Dark Matter



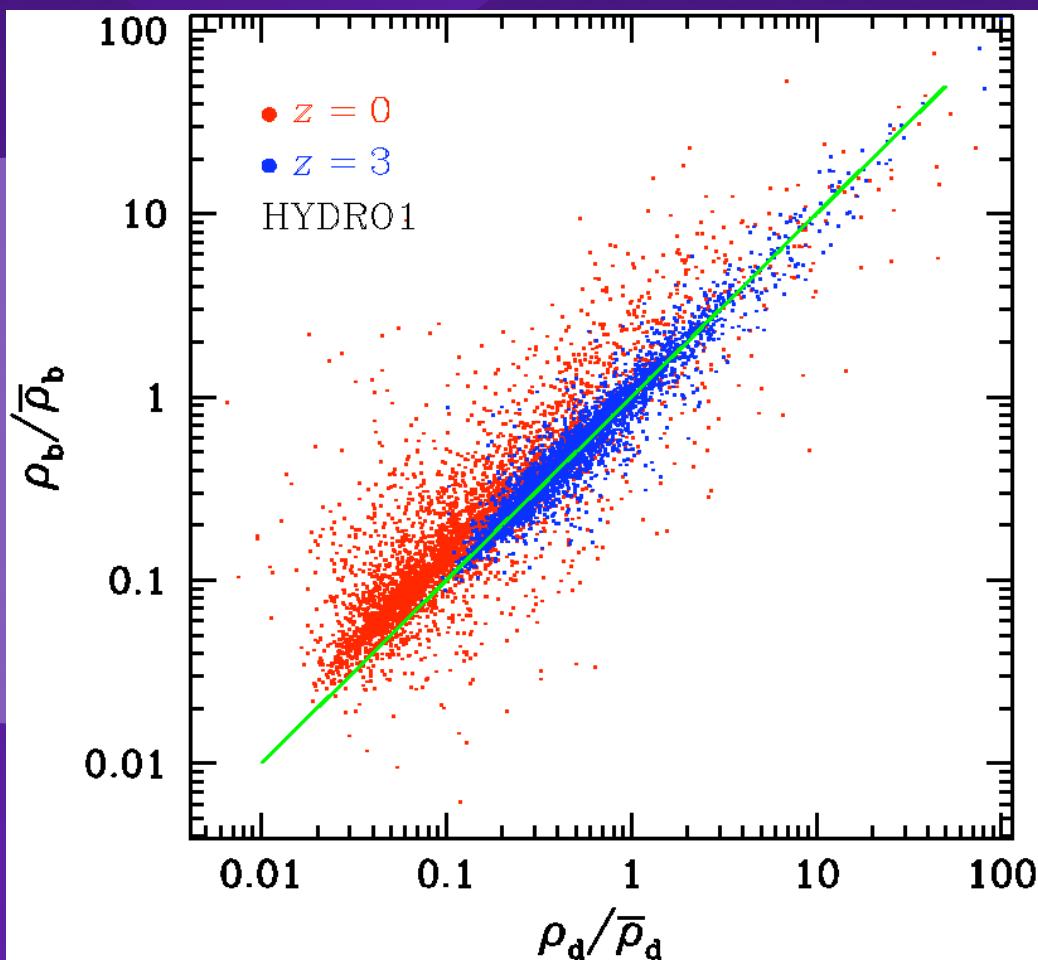
Gnedin & Hui (1998)

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- ④ Baryon fluctuation is suppressed by the linear filtering scale (same order as the Jeans scale).
- ④ Lines – linear evolution of perturbations in the dark matter-baryon fluid.
- ④ Points – different approximation of filtering.

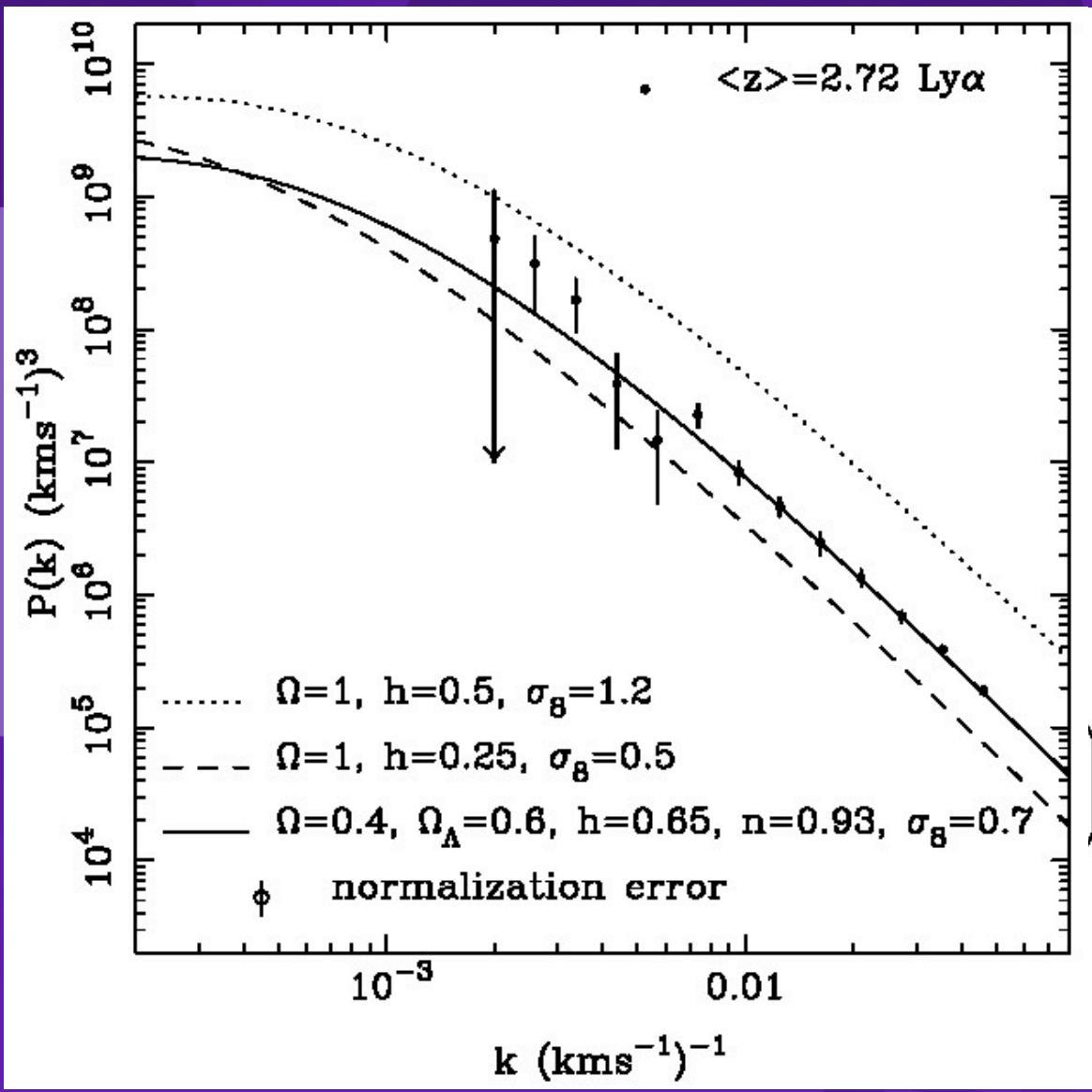
# Baryons vs. Dark Matter



- ⑧ LCDM TreeSPH  
(Davé et al. 1997)
- ⑧ Baryons trace  
dark matter

Zhan (2004)

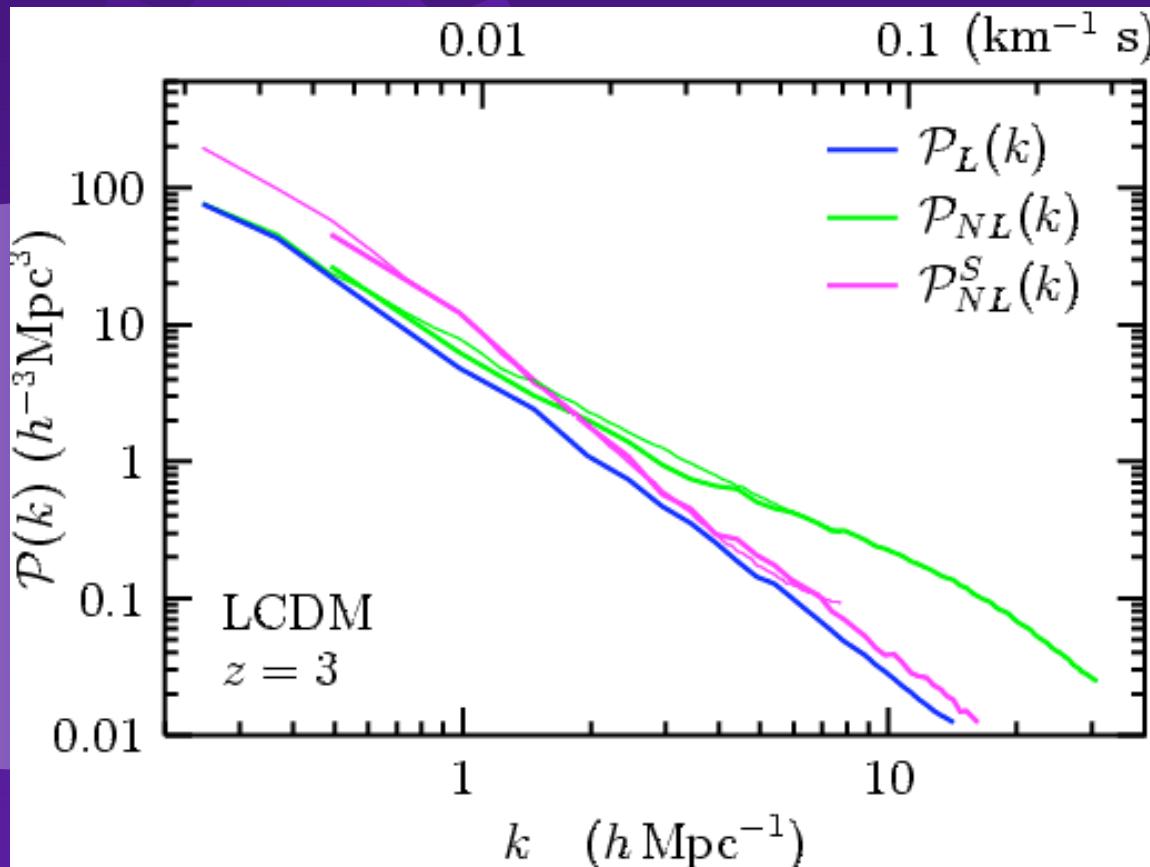
# Matter PS from the Ly $\square$ Forest



$$b^2(k) = \frac{P_F^{sim}(k)}{P^{sim}(k)}$$
$$P^{obs}(k) = \frac{P_F^{obs}(k)}{b^2(k)}$$

Croft et al. (2002)

# Power Spectra at $z = 3$



$$P_L(k) \rightarrow P_{NL}(k) \rightarrow P_{NL}^S(k) \rightarrow P_{1D}(k_3) \rightarrow P_F(k_3)$$

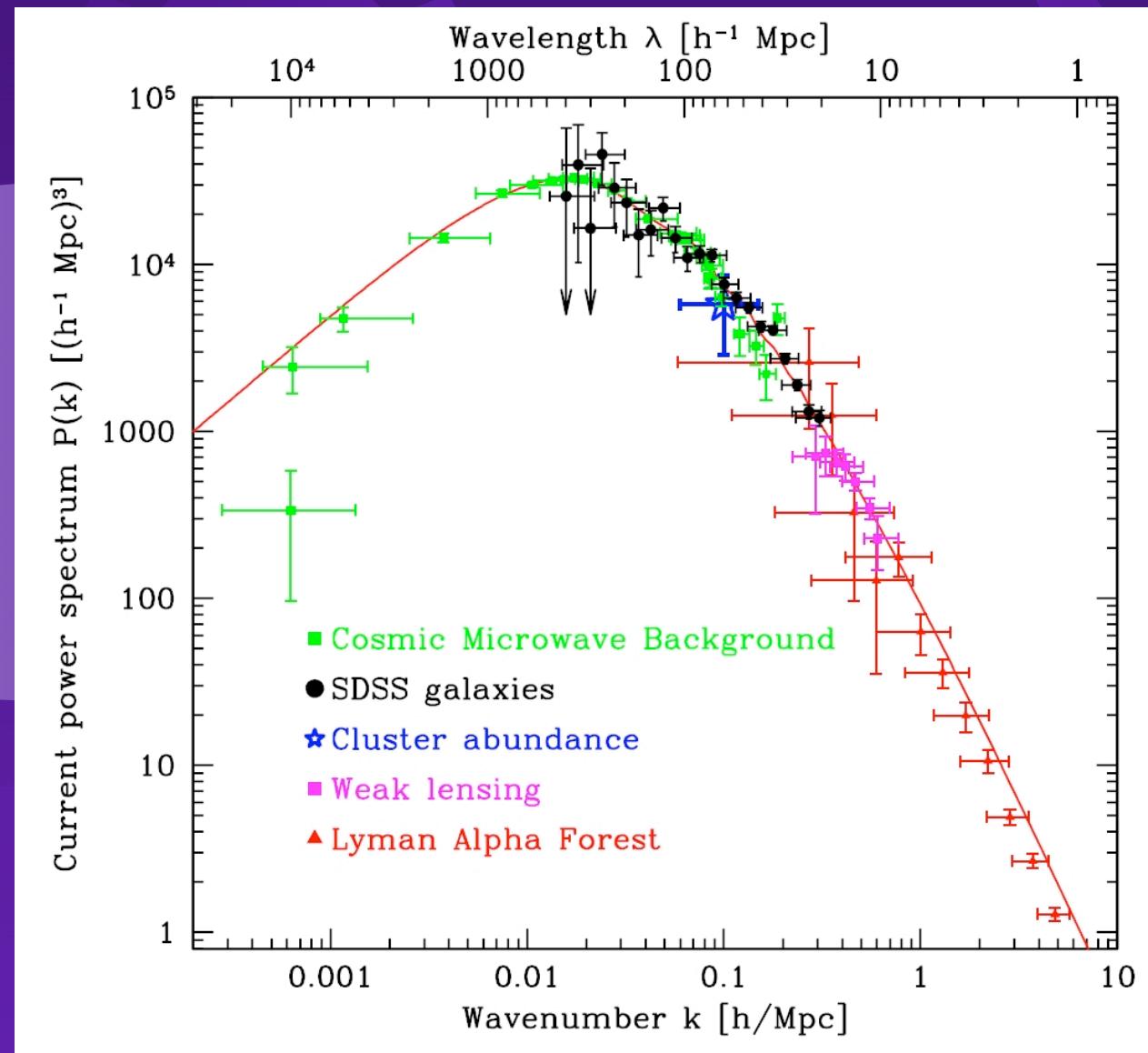
Zhan (2003)

$$P_L(k) \xrightarrow{b^2(k)} P_{F,3D}(k) \rightarrow P_F(k_3)$$

Croft et al. (2002)

- ∅ Non-linear evolution
- ∅ Redshift distortion

# Matter Power Spectrum

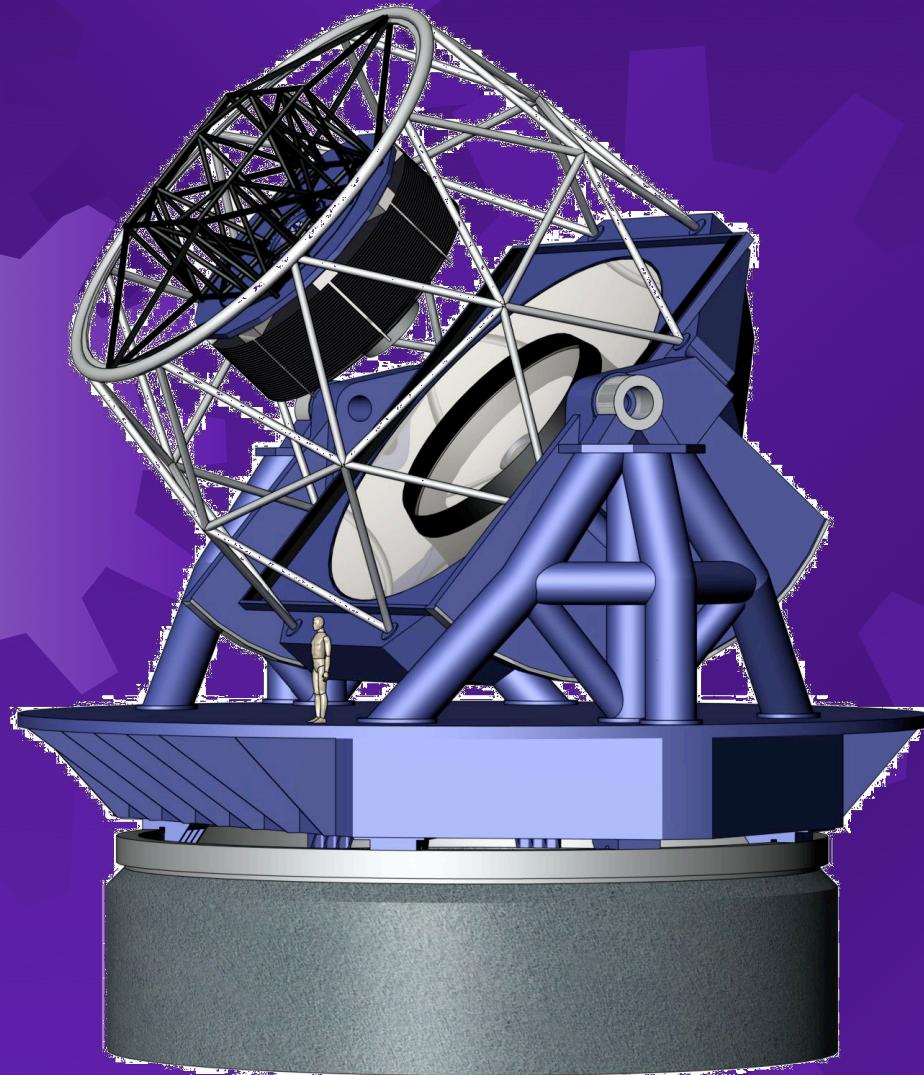


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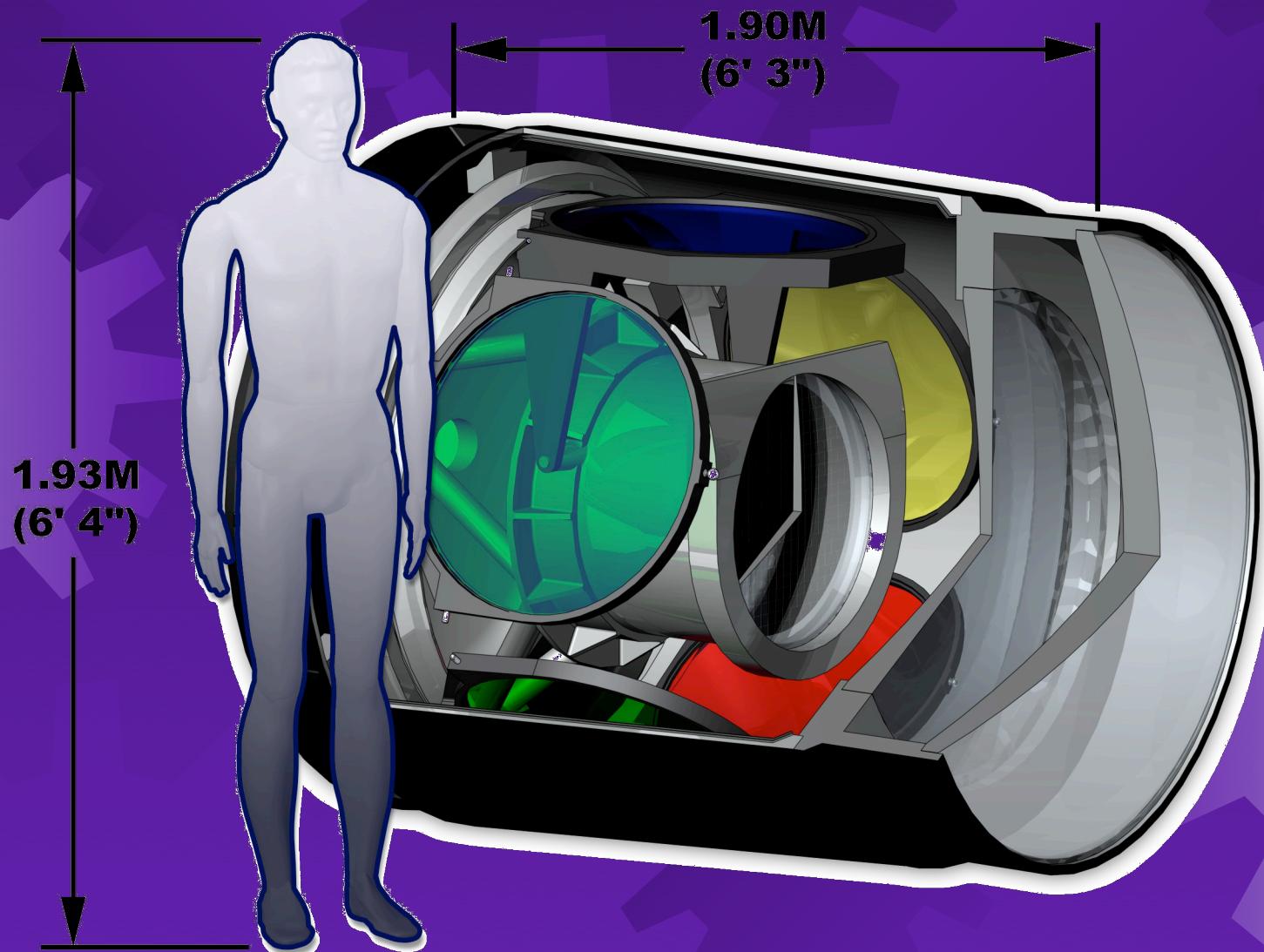
Tegmark et al.  
(2004)

# The Large Synoptic Survey Telescope



- 8.4-meter primary
  - 10 deg<sup>2</sup> field of view
  - 3 billion pixels
  - 0.3 - 1 μm
  - 20,000 deg<sup>2</sup> survey area
- 200,000 mag/deg<sup>2</sup>

# LSST Camera



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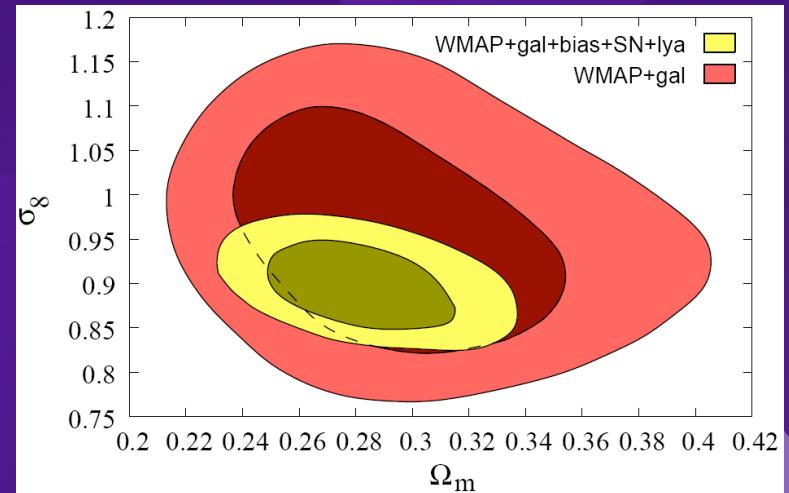
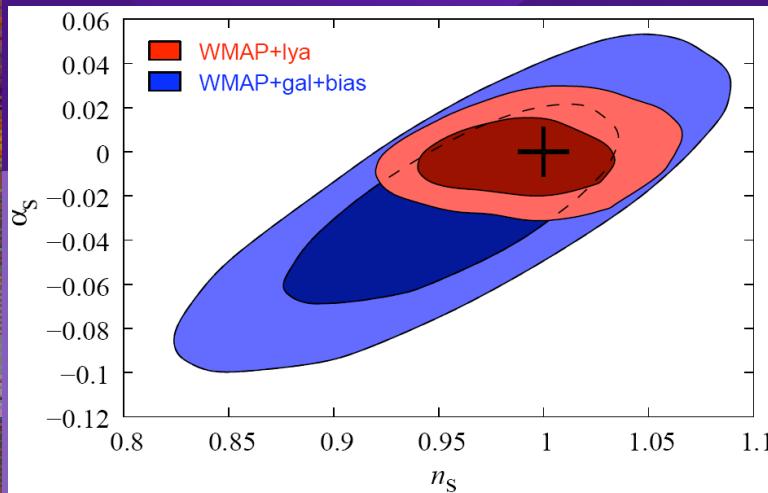
# Cosmological Parameters

Spergel et al. (2003):  $\Omega_8 = 0.84 \pm 0.04$ ,  $n_S = 0.93 \pm 0.03$ ,  
favors  $\Lambda$

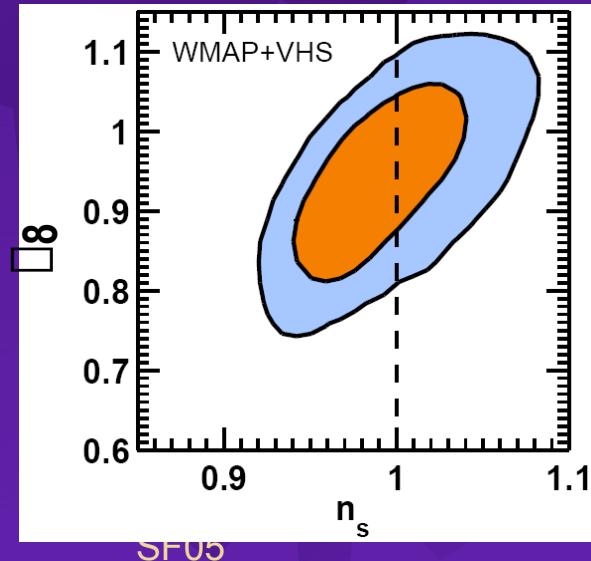
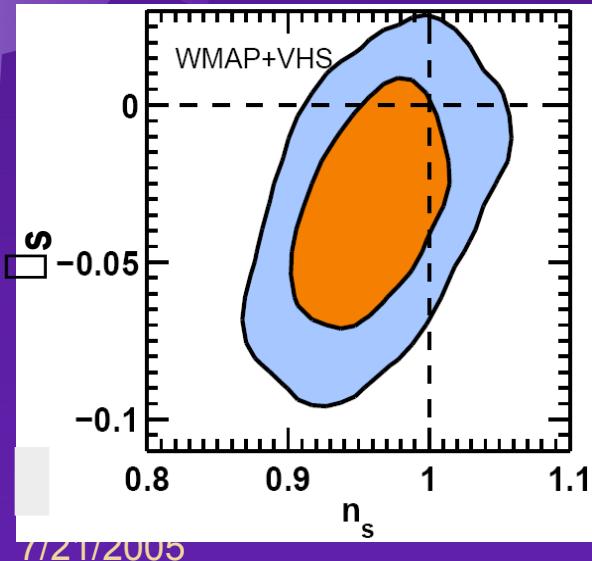
Viel et al. (2004):  $\Omega_8 = 0.94 \pm 0.08$ ,  $n_S = 0.959 \pm 0.036$ ,  
 $\Gamma = -0.033 \pm 0.025$

Seljak et al. (2005):  $\Omega_8 = 0.90 \pm 0.03$ ,  $n_S = 0.98 \pm 0.02$ ,  
 $\Gamma = -0.003 \pm 0.010$

# Cosmological Parameters

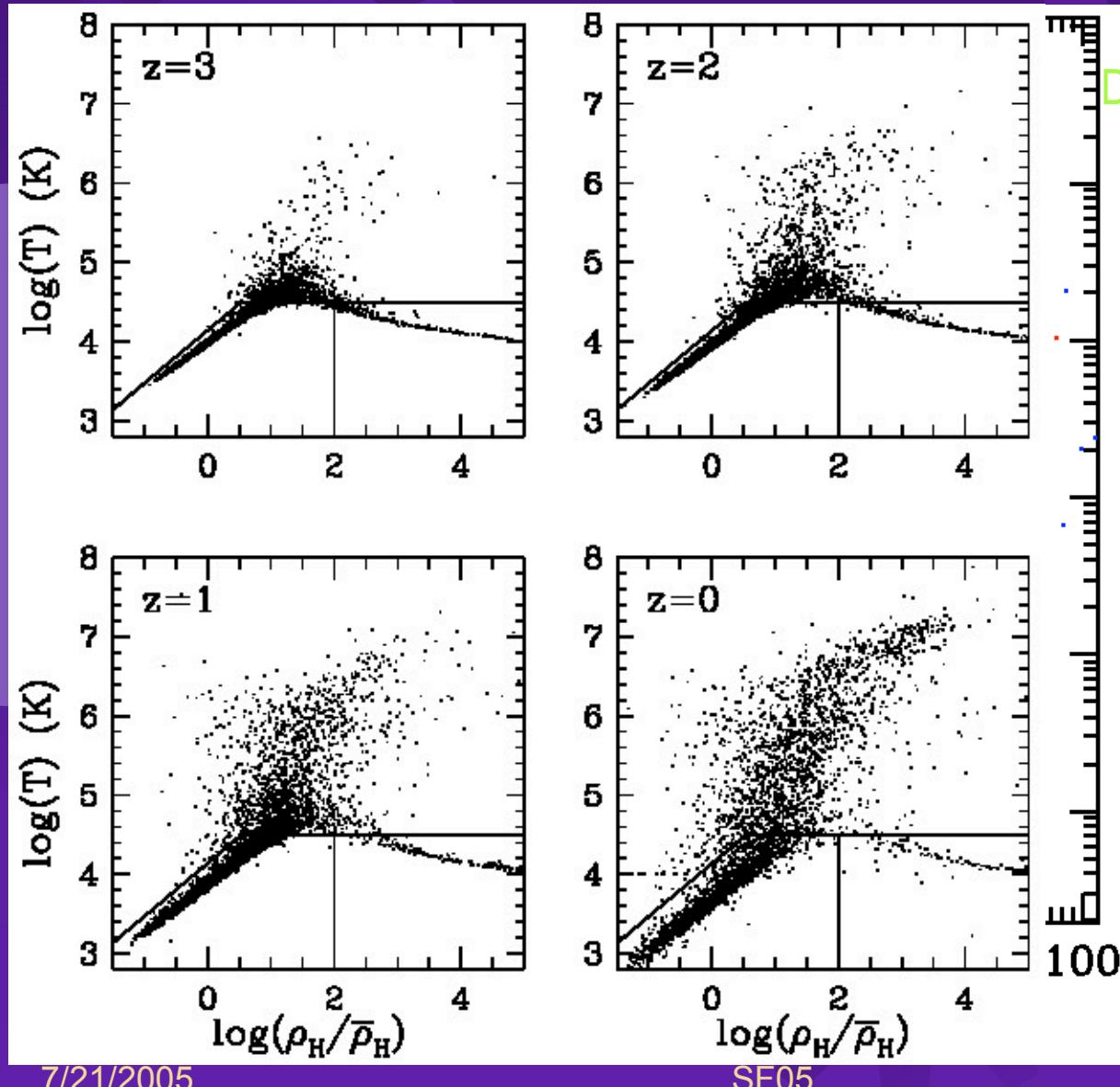


Seljak et al. (2005)



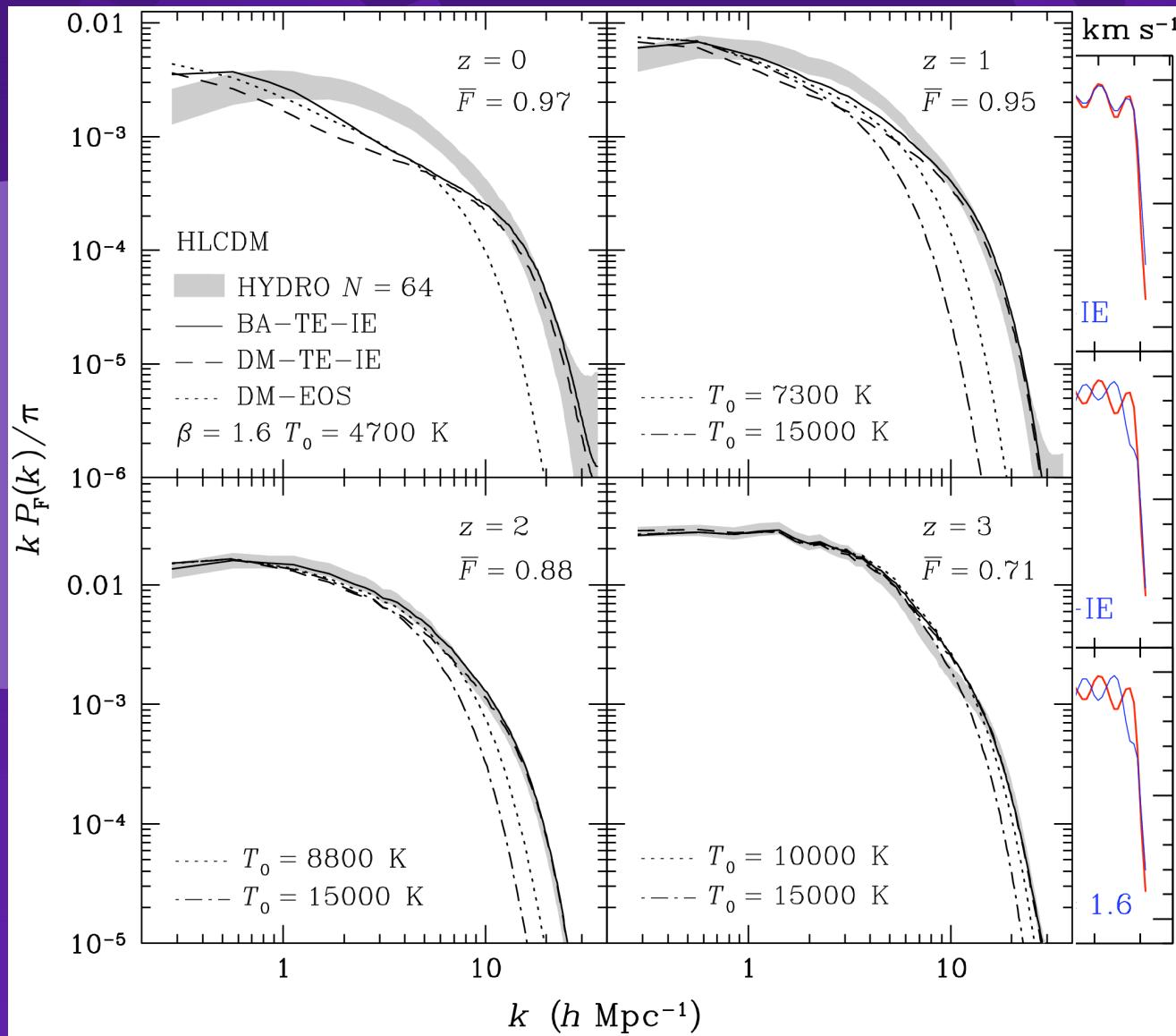
Viel, Weller, & Haehnelt (2004)

# The Warm-Hot Intergalactic Medium



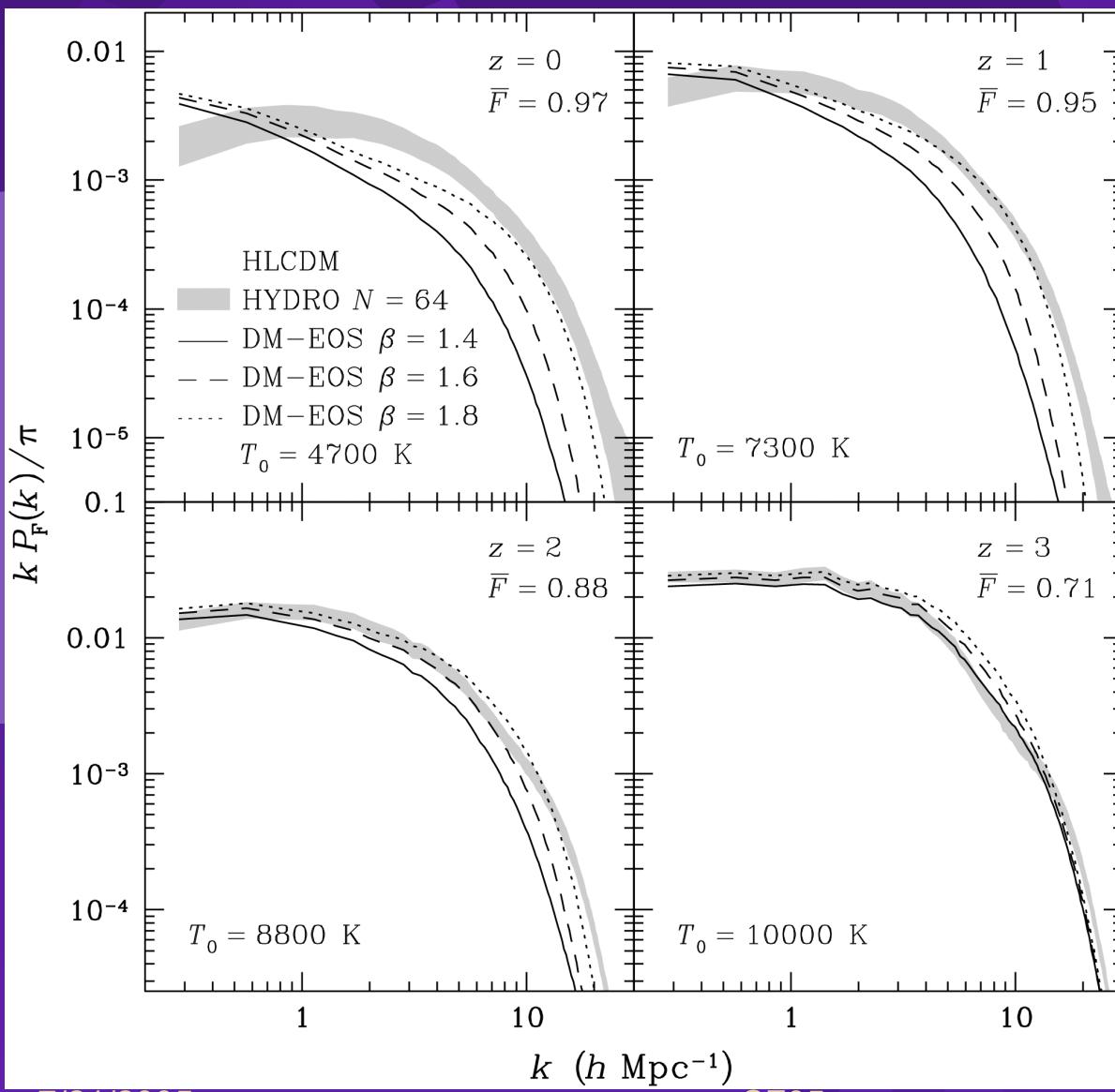
Davé et al. (1999)

# Pseudo-Hydro vs Full-Hydro

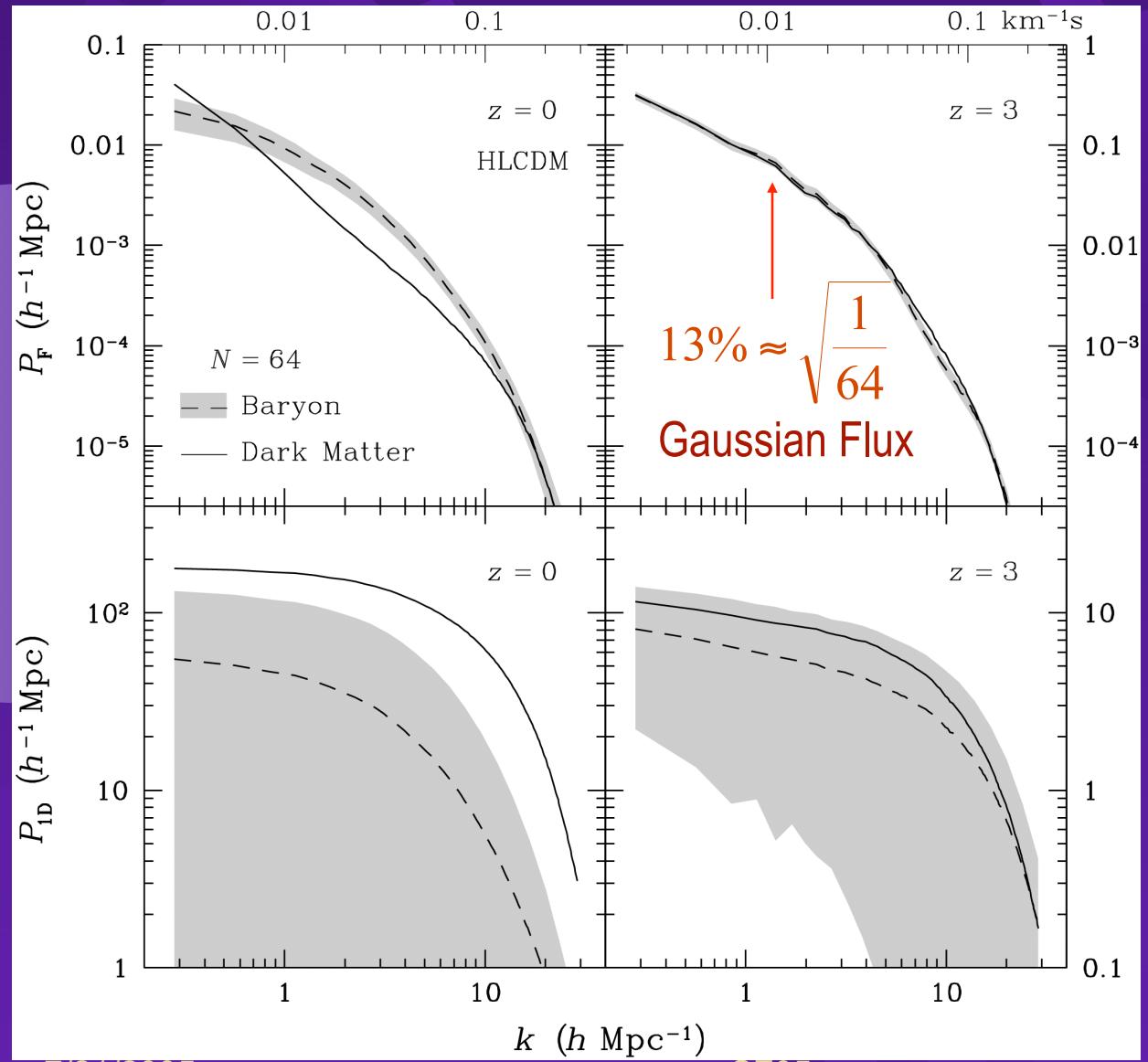


HZ, Davé,  
Eisenstein, & Katz  
(2005)

# Equation of State



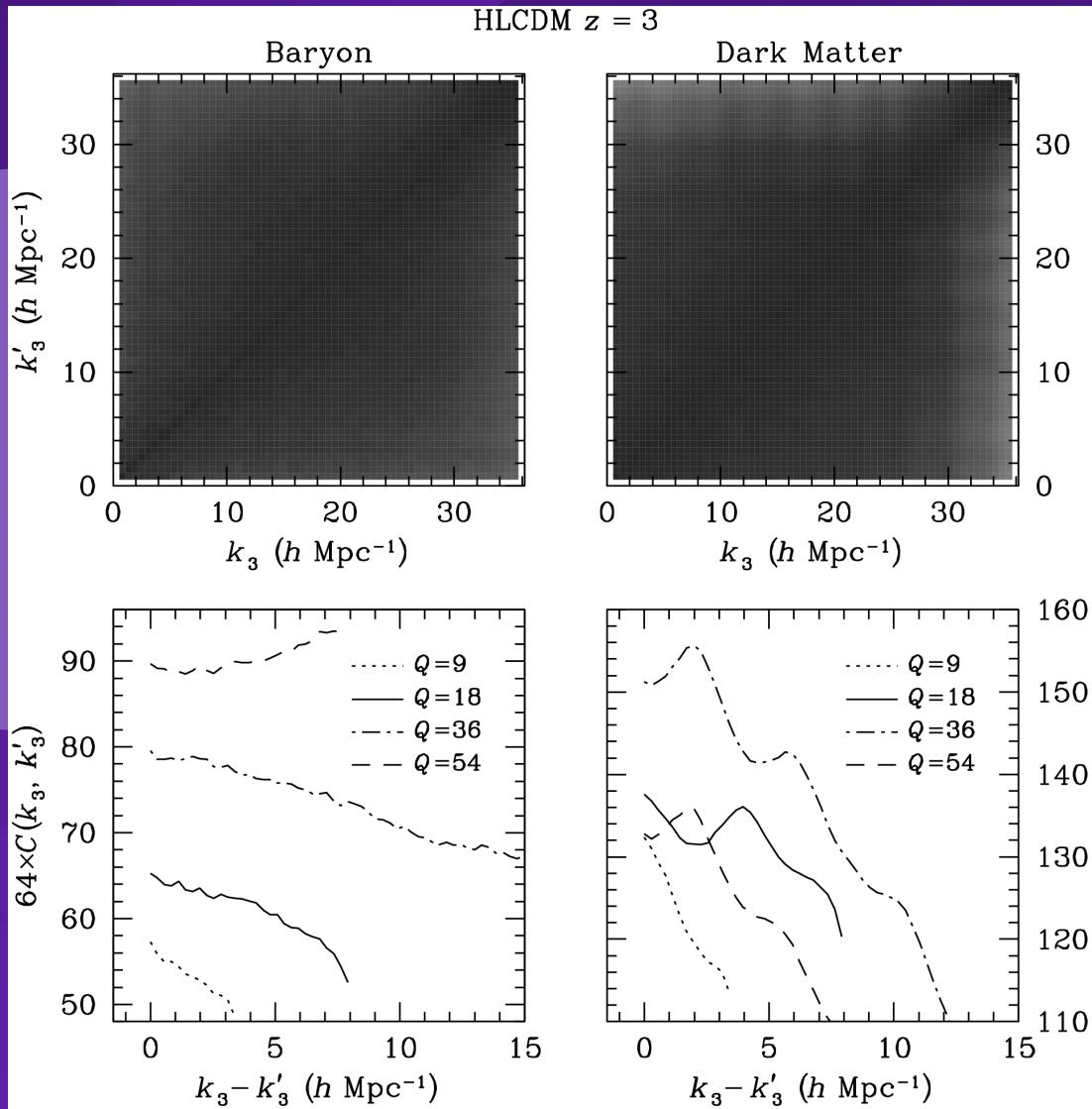
# Mass vs. Flux



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# Covariance: Mass at $z = 3$



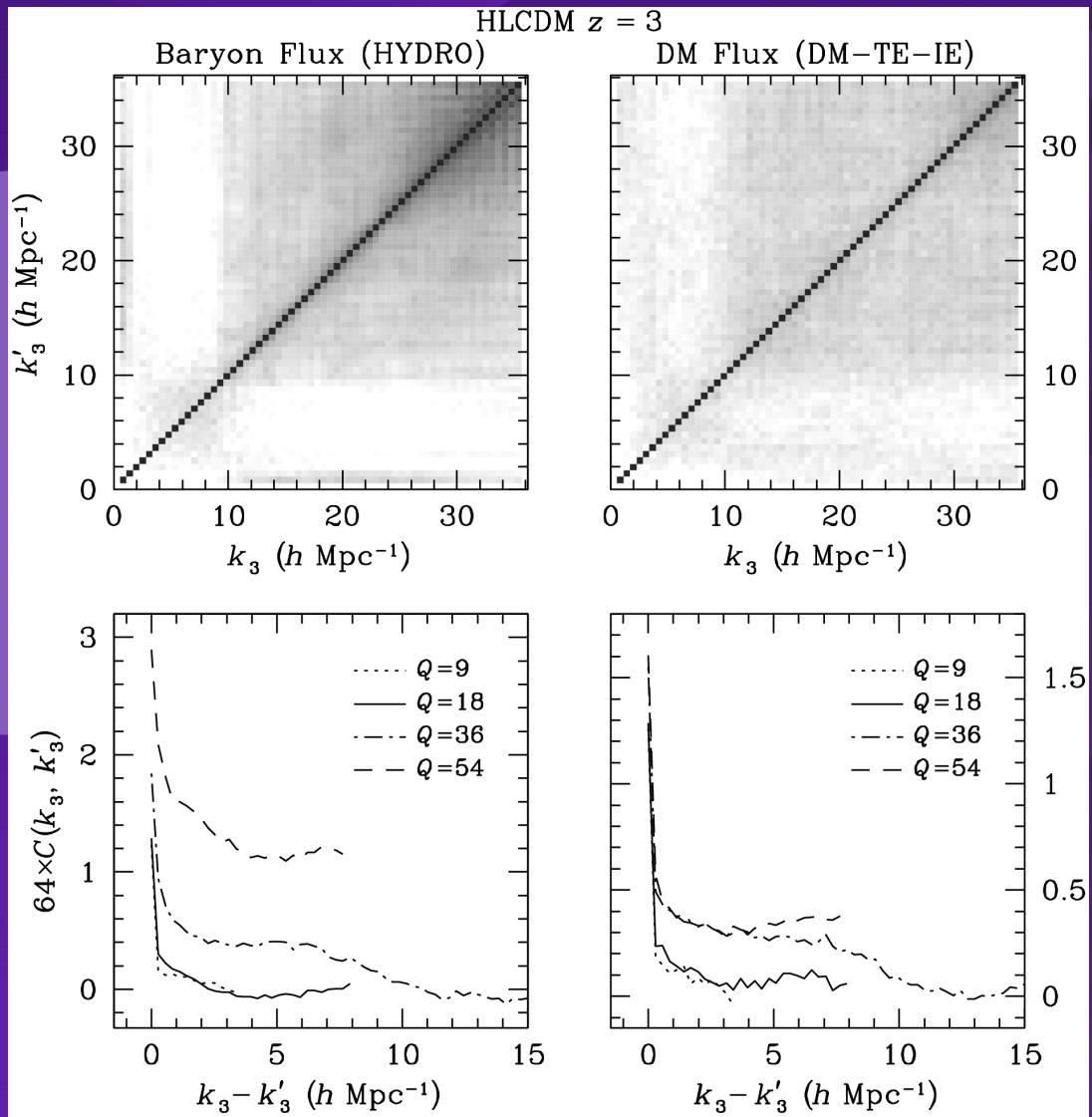
$$C(k_3, k_3') = \langle [P_{\text{1D}}(k_3) - \langle P_{\text{1D}}(k_3) \rangle] [P_{\text{1D}}(k_3') - \langle P_{\text{1D}}(k_3') \rangle] \rangle$$

$$\hat{C}(k_3, k_3') = C(k_3, k_3') C(k_3, k_3')^{-1/2}$$

$$C(k_3', k_3')^{-1/2}$$

$$Q = (k_3 + k_3')/(h \text{ Mpc}^{-1})$$

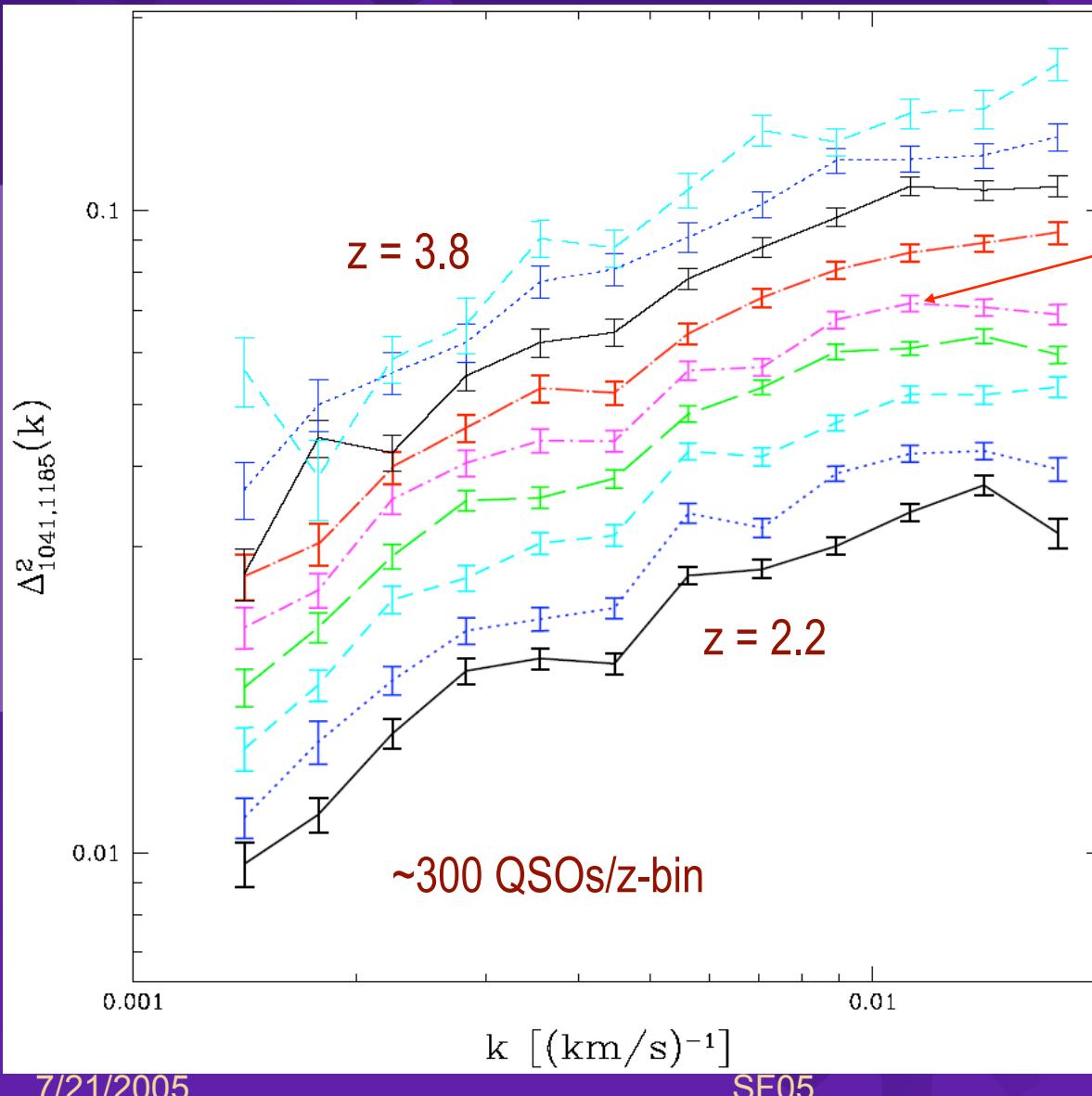
# Covariance: Flux at $z = 3$



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# SDSS Ly $\alpha$ Forest Flux PS



3.5% error

$dk = 10^{-4} \text{ km}^{-1}\text{s}$

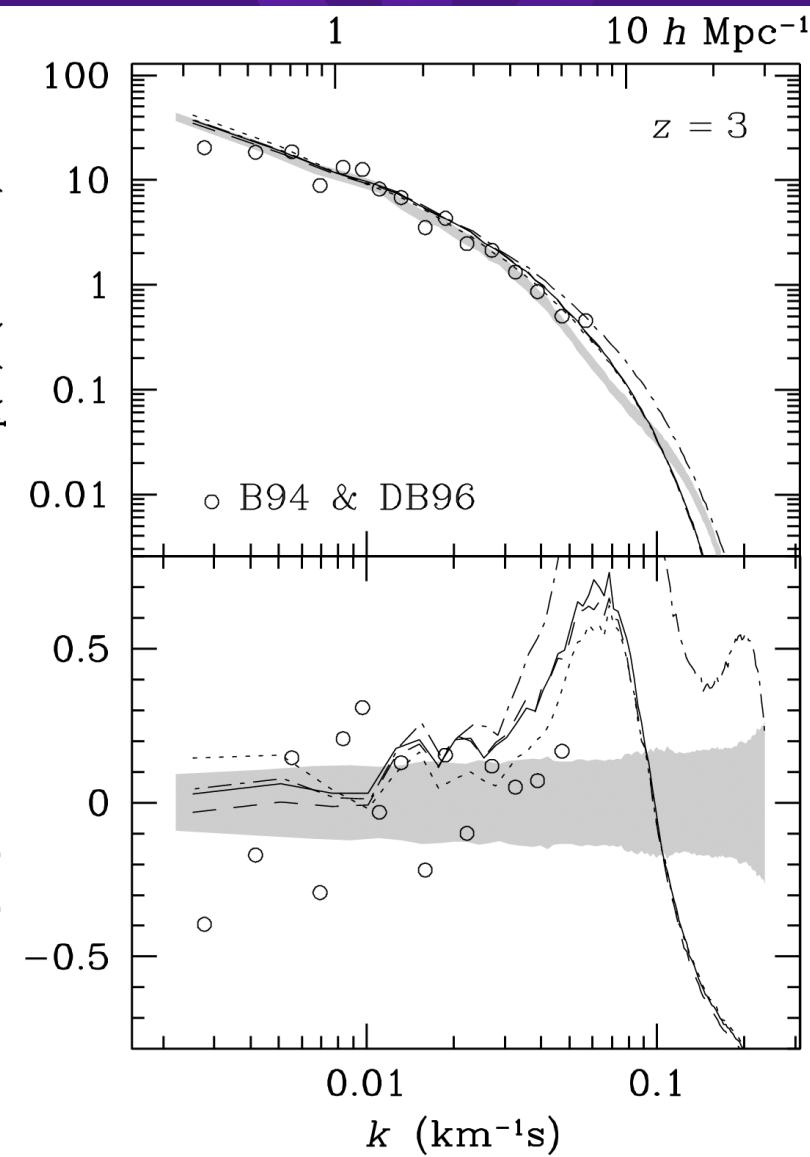
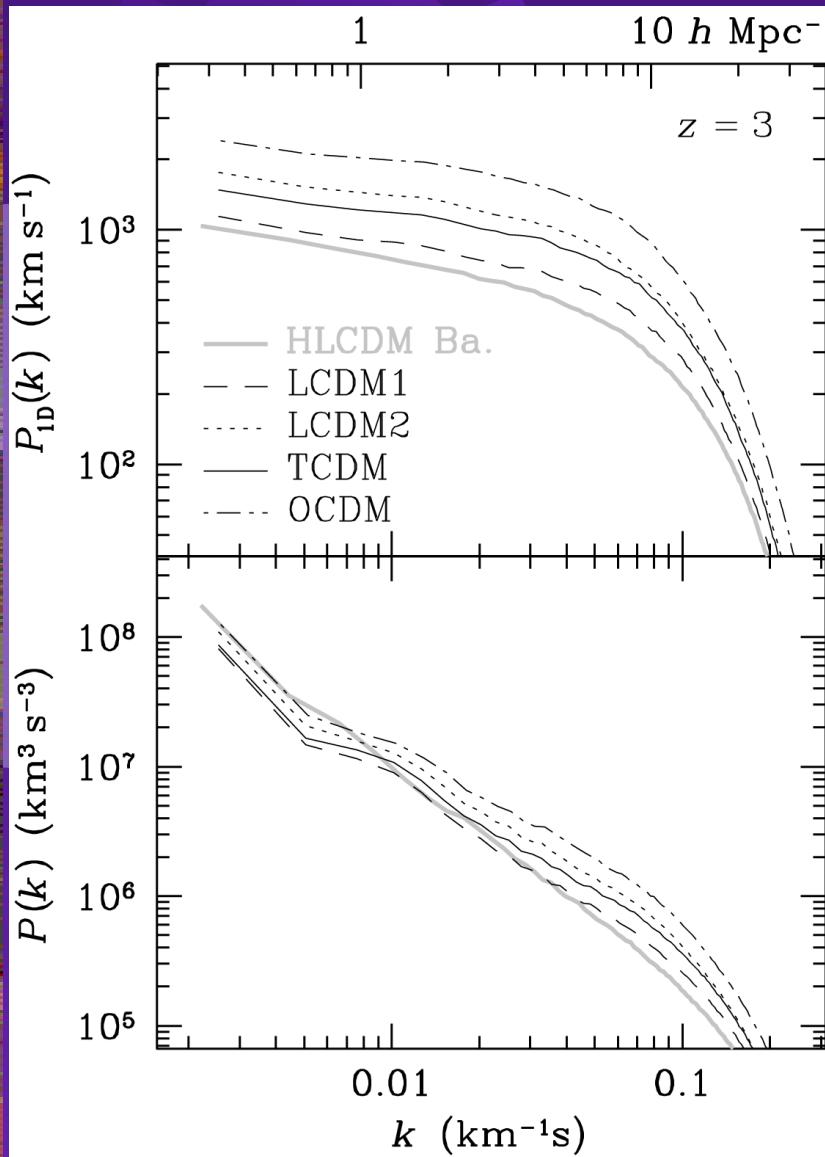
$\square k \sim 0.3 k \text{ (binning)}$

Statistical error:

$$\sqrt{\frac{2dk}{\Delta k} \frac{1}{N_{\text{QSO}}}} = 1.4\%$$

McDonald et al.  
(astro-ph/0407377)

# Cosmological Models



# More Systematics

- ⑧ Continuum fitting
- ⑧ Nonlinear evolution
- ⑧ Strong discrete absorptions
- ⑧ UV background fluctuations
- ⑧ Metal lines
- ⑧ Galactic winds
- ⑧ One-dimensional sampling

(Hui et al. 2001; Zaldarriaga, Scoccimarro, & Hui 2003; Zhan 2003; Viel et al. 2004;  
Meiksin & White 2004; McDonald et al. 2004a,b; Zhan & Eisenstein 2005)

# Summary

- ⑤ Pseudo-hydro techniques, especially at low redshift or on small scales (less than a few Mpc/h), are not accurate enough for precision cosmology.
- ⑤ The mass PS has significant cosmic variance. Modes are strongly correlated.
- ⑤ The Ly $\alpha$  flux PS is mildly non-Gaussian and not very sensitive to cosmology.
- ⑤ Systematic errors are the dominant source of error in the Ly $\alpha$  flux PS.
- ⑤ Inverting the Ly $\alpha$  forest?